Comparison of foliar nutrient concentrations between natural and artificial forests of *Pinus sylvestris* var. *mongolica* on sandy land, China

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Abstract: In order to examine the causes of degradation of *Pinus sylvestris* var. *mongolica* plantations on sandy land, the foliar concentrations of N, P, K and C were analyzed and compared between the field grown *P. sylvestris* var. *mongolica* trees from two provenances (natural forests and plantations). The results indicated that natural tree needles had lower N, P and C concentrations, and higher K concentrations than those of plantation tree needles. For plantation tree needles, ratios of N: P, P: K and N: K increased with tree age before 45 years old; but they were not clear for the natural tree needles. Compared with the conclusions reported on *Pinus* spp., we found that the foliar N and P concentrations were in the optimal range for both natural and plantation tree needles. This result suggested that N or P might not be the absolute limit factors in plant nutrient for *P. sylvestris* var. *mongolica* on sandy land. However, foliar K concentrations in both natural and plantation tree needles were much lower than those reported on *Pinus* spp. (>4.80 g kg-1).The N: P ratio of natural needles was in the adequate ranges, but N: P ratio of plantation needles was out of the adequate ranges. These results indicated that there was a better balanced nutrition status in the natural forest than in the plantations. If only considering the foliar nutrient concentrations of *P. sylvestris* var. *mongolica* from different provenances, it might be concluded that the degradation phenomenon of *P. sylvestris* var. *mongolica* plantations was not induced by nutrition deficiency of absolute nutrients of N and P, but might be induced by other mineral nutrients or by the effectiveness of N and P nutrients. The unbalanced nutrition status and relatively quick decomposition of needles in the plantations might also contribute to the degradation.

Key words: Degradation phenomenon; Forest ecosystem on sandy land; N: P ratio; Natural Mongolian pine; *Pinus sylvestris* var. *mongolica*; Plantation Mongolian pine
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Introduction

Mongolian pine (*Pinus sylvestris* L. var. *mongolica* Litv.), a geographical variety species of Scots pine (*P. sylvestris*) (Jiao 1989; Kang *et al*. 2004), is an important tree species of afforestation in the protective plantation forests. It was first introduced to plant in southern Keerqin sandy land of China (N42°39.7′, E122°33.6′) in spring of 1955. After the primary success of the tree species introduction, Mongolian pine plantations have been widely developed on sandy land because of the cold-resistance (–40°C to –50°C), drought resistance and broad adaptation of the tree species (Zhao and Xu 1963; Zeng *et al*. 1996). The area of its plantation on sandy land has reached more than 3.00×10^5 hm^2 (Kang *et al*. 2004; Zhu *et al*. 2005b). But since the late of 1980s, the earliest Mongolian pine plantation (1.07×10^4 hm^2) which was introduced and established in 1950s in Zhanggutai, Zhangwu County, located at the south of Keerqin sandy land, the northwest of Liaoning Province of China, occurred decline phenomena. It was characterized with top withered, lower growth, disease or insects, and dead stems (Jiao 1989; Zhu *et al*. 2003; Zhu *et al*. 2005b). However, the natural stands on sandy land (in Honghuaerji, Hulunbeier sandy plain, Mongolian Autonomous Region, China) have exhibited a healthy situation at the same stage of plantations (Zeng *et al*. 2002; Zhu *et al*. 2003). There have been many assumptions introduced to explain the causes of the decline (Jiao 1989; Zeng *et al*. 1996; Wang *et al*. 1999; Jiao 2001; Liu *et al*. 2002; Zhu *et al*. 2005a), but till now no specific theories could successfully interpret this phenomenon (Chen *et al*. 2004). In general, water conditions and nutrients are often considered to be the key factors influencing the plantation decline (Barron-Gafford *et al*. 2003).

Successful determination on the causes of the decline might help understanding the relationships between decline and many biotic and abiotic factors. One of the fundamental aspects of the decline-biotic/abiotic relationship is tree nutrition (Wang and Klinka 1997). Foliar analyses are effective methods for nutrient deficiency diagnosis (Thompson *et al*. 1997; Wang and Klinka 1997; Xiao *et al*. 2003; Tausz *et al*. 2004). Reported research indicated that nutrients induced growth restrictions were detectable by comparing foliar nutrient concentrations to the threshold ranges (Regina *et al*. 2001; Tausz *et al*. 2004). The foliar nutrient concentrations of trees were important parameters to assess the nutritional status of forests (Koerselman and Meuleman 1996; Tausz *et al*. 2004; Chen *et al*. 2004). In particular, for forest trees, nutrient contents of each tissue provide an accurate reflection of the nutritional status whereas the value of soil analysis is limited (Tausz *et al*. 2004). The relationships between foliar nutrient concentrations and site index, soil nutrients and the responses of foliar nutrient concentrations to fertilization have been studied in various forests (Boerner 1985; Judd *et al*. 1996; Wang and Klinka 1997; Jiang and Yu 2000; Zhou and Wen 2000; Pugnaire 2001; Sun and Chen 2001; Willby *et al.* 2001; Karlsson and O¨rlander 2002; Tessier and Raynal 2003). These studies suggest

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that foliar nutrient concentrations are useful indicators of site quality and /or productivity, and significant correlation existed between foliar nutrient concentrations and various measures of forest growth and productivity.

However, few studies reported foliar nutrient concentrations of Mongolian pine trees both in natural and plantation forests. In order to explore the nutrient causes of plantation decline through analysis of the differences of foliar nutrient concentrations between Mongolian pine trees in natural and plantation forests, we hypothesized that: (1) foliar nutrient concentrations would be different between the two provenances of Mongolian pine trees because the foliar nutrient concentrations reflect the nutritional status of forests; (2) the ratios of N:P or K in needles give the indication of the relative availability of these nutrients in the soil, which Koerselman and Meuleman (1996) indicated that thresholds of N: P ratio in needle nutrient contents would be unbalanced in Mongolian pine plantations because of Liebig's Law of the Minimum, although the decline of Mongolian pine trees in plantations might be partly due to low soil nutrient content, soil water deficiency and microbe disappearance or the comprehensive impacts from all of the ecological factors in the area (Zhu *et al.* 2003). Such comparison results might partially provide evidences for afforestation and management of large-scale man-made Mongolian pine plantations on sandy land.

Materials and methods

Site description

The experiment about Mongolian pine was carried out at two sites: the natural forest site (N48°8.801′–12.569′, E119°55.955′–120°2.690′) and the plantation site (N42°39.712′–43°44.620′, E122°30.702′–123°33.768′). The former is located in Hulunbeier sandy land, Honghuaerji of Inner Mongolian Autonomous Region (NHHI), and the later is located in Keerqin sandy land, Zhanggu County of Liaoning Province (PKSL), China, which was the earliest location for Mongolian pine introduction. The natural Mongolian pine forests on sandy land in NHHI became the National Nature Reserve Area (NNRA) in 1998. The total area of the NNRA is 20 085 hm^2; the forest coverage is 83.5%. The precipitation and evaporation in NHHI are 378 mm and 1 174 mm, but in PKSL those are 496 mm and 1 700 mm, respectively. For the natural forest site, annual mean temperature is –3.7°C, absolute minimum temperature is –45.0°C, effective accumulated temperature (≧10°C) is 2 000°C and frostless days are 90 days, but those for plantation forest site are 5.9°C, –30.4°C, 3 067–3 148°C and 160 days, respectively. Soil type in NHHI is pine sandy soil and soddy sandy soil (≥ 0.01 mm, 91.7%, <0.01 mm, 8.3%). Average depth of land is in the range of 0–90 cm. Soil available nitrogen is in the range of 0.2–0.3 $g·kg^{-1}$ and soil available phosphate is in the range of 0.1–0.15 $g·kg^{-1}$. In PKSL soil type is mobile sandy soil and soddy sandy soil (≥ 0.01 mm, 94.0%, <0.01 mm, 6.0%). Average depth of land is in the range of 0–107 cm. Soil available nitrogen is in the range of 0.3–0.4 $g·kg^{-1}$ and soil available phosphate in the range of 0.1–0.11 $g·kg^{-1}$ (Zhu *et al.* 2003; Chen *et al.* 2004). The plant species in natural forests are more multiple than those in plantations, the dominant species under the canopy are shrub, such as *Filifolium sibricum*, *Stipa baicalensis*, *Festuca ovina*, *Carex pediformis* in natural forests, but in plantations, the dominant species are herb, such as *Agropyron cristatum, Arundinella hirta*, *Cleistogenes chinensis* (Zhu *et al.* 2003; Zhu *et al.* 2005b)

Needle sampling

In order to investigate the effects of tree age on foliar nutrient concentrations in Mongolian pine needles, we collected needle samples from various age gradients of trees from two sites, respectively, during July 27 and August 10 of 2004. Four and five plots were selected in NHHI and PKSL, respectively, in which the sites appeared as evenly as possible. All trees within the sample stands (more than 400 m^2) were measured. The measured items included number of trees (stand density), tree height, and diameter at breast height (DBH). The age of the mean stem was determined using increment borer for natural stands, and determined by referencing the local forestry archives for plantation stands, respectively.

The number of trees in each age-gradient sampled for nutrient analysis varied between provenances, but was never less than three; and the sample stands were all on the flat sandy land. Because of the uneven-aged stand in NHHI, needle samples from NHHI were collected in the sample plots of No.2, No. 4, No. 8 and No.9, in which the tree ages were included 30, 35, 40, 50, 70, 90 and 200 years , respectively. In the plantations, five different age-gradient trees in PKSL were selected (Table 1). For each experimental tree, mature, non-senescent needles were collected. All the existing age-class leaves (first, second and third-year needles) of two branches (first-order branches from the same height in the south direction) were taken (Table 1).

Table 1. Mean stand characteristics of plots for needle sampling

	Sample tree age (year)	Code	Sample plot number	Plot area (m^2)	Stand density ($stem·hm^{-2}$)	Mean stand age (year)	Mean DBH (cm)	Basal area ($m^2·hm^{-2}$)
Natural stands	30	TN1	No.2	1250	536	65.0	19.9	27.15
	35	TN2	No.2					
	40	TN3	No.4	400	5675	32.0	8.1	44.86
	50	TN4	No.9	900	1367	51.0	9.5	43.54
	70	TN5	No.8	1600	238	86.0	35.0	23.57
	90	TN6	No.2					
	200	TN7	No.4					
Plantation stands	10	TP1	No.1	900	1500	10.0		
	20	TP2	No.2	900	1322	20.0	11.7	14.21
	25	TP3	No.3	900	656	25.0	13.3	9.11
	30	TP4	No.4	900	378	30.0	13.6	5.49
	45	TP5	No.5	900	200	45.0	24.2	9.19

Nutrient concentration analysis

Traditionally, the factors that limit plant growth at a community level are established in a factorial fertilizer experiment with major nutrients nitrogen (N), phosphorus (P) and potassium (K) (Koerselman and Meuleman 1996), therefore, we analyzed the concentrations of N, P and K in needles. The needle samples were divided into three groups, i.e., first, second and third-year needles. At first, the fresh needle samples were washed for one minute with demineralized water to remove dust (Chen *et al*. 2004), then, oven-dried to constant weight (about 48 hours) at 80 °C, and finely milled and screened with a 0.25 mm sieve. The samples were digested using the Kjeldahl method with hydrogen peroxide and sulphuric acid (320°C), and a selenium mixture catalyst (Tausz *et al*. 2004) for determining foliar concentrations of K and P. Foliar K concentration was measured by flame ionization using Model 6400-A analyzer (Shanghai, China), and total phosphorus concentration was determined colorimetrically by using Model 721 spectrophotometry (Shanghai, China). Total nitrogen (N) and organic carbon (C) concentrations were determined by a Technicon autoanalyser using ELEMENTAR (Vario EL III, Germany).

Data analysis

The relationships between the foliar nutrient concentrations and tree age, the comparisons among N, P and K in natural and plantation stands, and the determination of differences among mean values in each stands were tested by analysis of variance (ANOVA). The mean values of foliar nutrient concentrations in the three groups were calculated as the total mean values.

Results

Change of foliar nutrient concentrations along age gradients

Foliar N, P and K concentrations of Mongolian pine needles had not significant differences (p<0.05) among 1, 2 and 3-year needles for both natural and plantation tree needles (Fig.1). But foliar N concentration in plantation tree needles ranked with 1-year needles>2-year needles>3-year needles before 40 years old (Fig.1A_p). The mean values of foliar N concentration in plantation tree needles were significantly higher than those of in natural tree needles (solid line in Fig. 1A_p, A_n), i.e., 15.105 and 12.125 g·kg^{-1}, respectively, but there was not a clear tendency for foliar P and K concentrations (Fig.1B_p, B_n; C_p, C_n). The mean values of foliar N, P and K concentrations decreased with age before 25 years, and then increased after this age for plantation tree needles (Fig 1A_p, B_p, C_p). For the natural tree needles, foliar N concentration showed the same tendency as the plantation trees, it decreased with age before 40 years (Fig.1A_n). Although foliar P and K concentrations did not show the same tendency as foliar N concentration, both of them showed the same trends with age (Fig.1B_n, C_n).

Foliar N: P, P:K and N:K ratios

The foliar nutrient ratios were calculated with the mean values of foliar nutrient concentrations in different needle ages. For plantation tree needles, N:P ratio almost increased with the increasing of the tree age (Fig. 2A_p), P:K and N:K ratios increased with the increasing of the age before 45 years (Fig. 2B_p, C_p). However, the change trends of N:P, P:K and N:K ratios for natural tree needles with age were not clear (Fig. 2A_n, B_n, C_n). The variation of N:P ratios of natural tree needles were large (ranged from 6.620 to 21.245), but almost constant for plantation tree needles (around 10.000).

In order to identify the effects of tree ages on the nutrient concentrations and their ratios, we plotted the mean values of N:P, P:K and N:K ratios for both natural and plantation tree needles with the similar ages (the mean values from 30, 35, 40 and 50 years old for natural tree needles, and 30 and 45 years old for plantation tree needles) in Fig. 3. The results indicated that the mean values of N:P ratios with similar ages were not in significant difference between natural and plantation tree needles, but significant difference for the mean values of P:K and N:K ratios (p<0.05), i.e. the mean values of P:K and N:K ratios from natural tree needles were higher than those from plantation tree needles (Fig. 3).

Comparison of foliar nutrient concentrations between natural and plantation

The total mean values of foliar N, P and K, and N:P, N:K and C:N ratios were calculated and summarized in Table 2. There were significant differences in foliar N concentration, C concentration, N:P ratio and C:N ratio between the natural and plantation tree needles at p<0.05 level, but no significant differences in foliar P and K concentrations and N:K ratios (Table 2).

The C:N ratio can serve as a significant predictor of decomposition rate (Enríquez *et al*. 1993). Litter with low C concentration and high N concentration always decomposed quickly (Enríquez *et al*. 1993; Gholz *et al*. 2000). For many ecosystems, nutrient absorption from litter decomposition is an important process, so the C:N ratio is a good index to indicate the development of nutrient balance of forest ecosystems. In the natural forest, the C:N ratios increased with age after 70 years; but in plantations the values increased with age before 25 years (Table 2). So the decomposition rates of needles in plantations should be much quicker than those in natural forest (Berg *et al*. 1991). The result identified important status of nutrient cycling for Mongolian pine forests on sandy land.

Discussion

Foliar nutrient concentrations were recognized effective indicators of the nutritional status for many plant species (Boerner 1985; Kayahare *et al*. 1995; Alifragis *et al*. 2001; Chen *et al*. 2004), particularly, the foliar nutrient concentrations of trees are important parameters to assess the nutritional status of forests (Chen *et al*. 2004; Tausz *et al*. 2004). The restrictions of tree growth or forest decline induced by nutrition deficiency are detectable by comparing foliar nutrient concentrations to the threshold ranges (Regina *et al*. 2001; Tessier and Raynal 2003; Tausz *et al*. 2004). However, the threshold ranges are different among species. There were some conclusions indicated the threshold ranges for many tree species (Boerner 1985; Judd *et al*. 1996; Wang and Klinka 1997; Garrison *et al*. 2000; Karlsson and O¨rlander 2002; Rothe *et al*. 2003; Tausz *et al*. 2004), but no information on the threshold ranges for Mongolian pine forests (Table 3). According to the thresholds of N: P ratios in needles, the nutrient statuses can be categorized as P-limited, N-limited, N, P co-limited and not limited by N and P (Chen *et al*. 2004).

From the threshold values of foliar N and P concentrations in coniferous forests obtained in Europe and America (Table 3), the most closely related pine species to Mongolian pine is considered to be Scots pine (*P. sylvestris*) coming of Europe, but the complete foliar nutrient data for this species were not available. Reports of the thresholds of foliar N, P and K concentrations for

P. sylvestris indicated that N=11.62-14.29 g·kg^{-1}, P=1.31-1.48 g·kg^{-1} and K=4.82-5.29 g·kg^{-1} were below the optimum levels of the tree species (Karlssona and O¨rlander, 2002); the foliar N:P =8.96 for *P. sylvestris* was confirmed as N-limitation by Tessier and Raynal (2003). There were also other thresholds of N, P, K and N: P ratios established for some other *Pinus* species (e.g., *P. contorta*, *P. ponderosa*, *P. pinaster*, *P. halepensis*, *P. radiata*, *P. canariensis*, and *P. taeda*) (Zas and Serrada 2003) (Table 3).

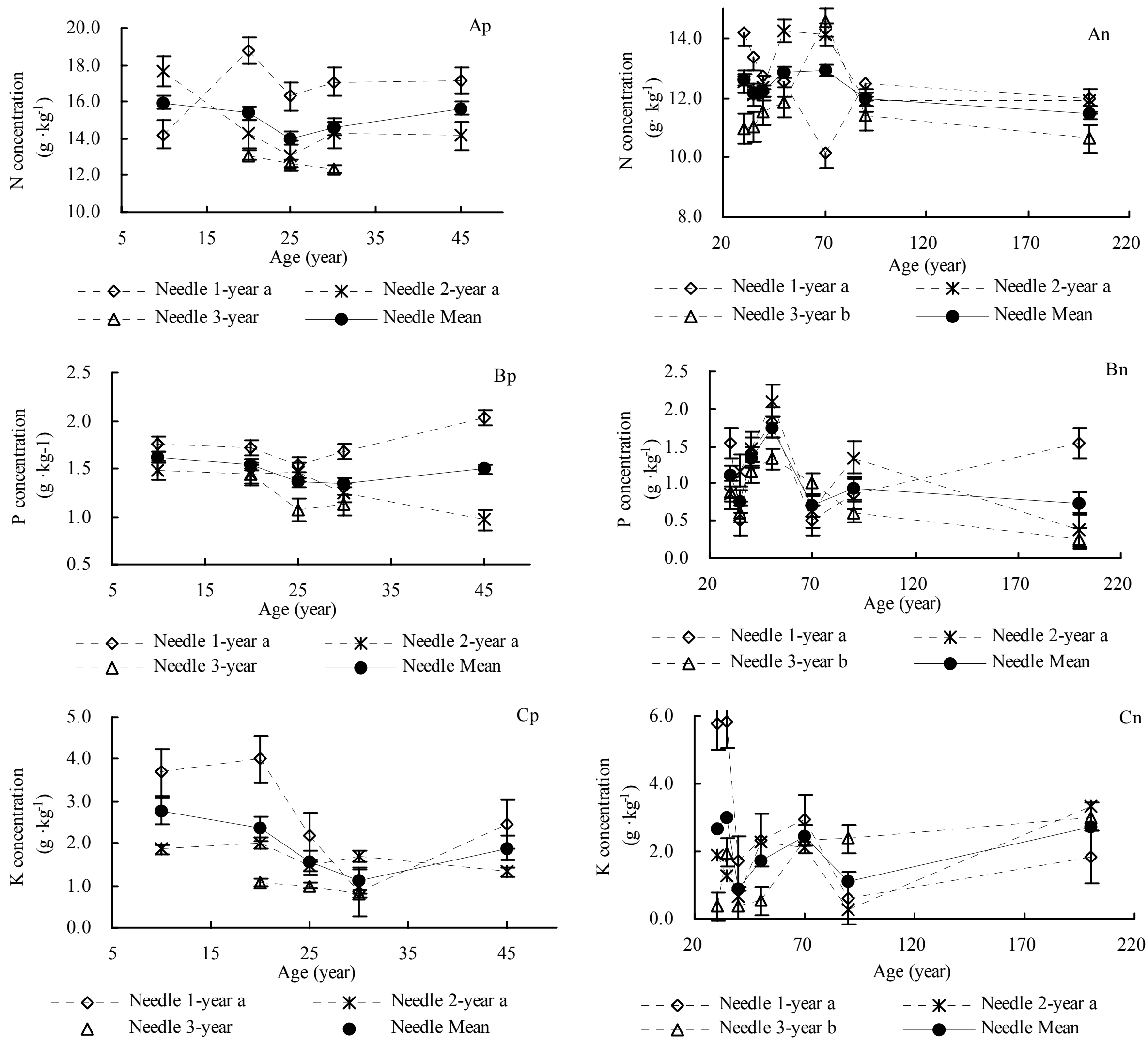

Fig.1 Variation in N, P and K concentrations according to age-gradients.

Note: (A_p, A_n) N concentrations, (B_p, B_n) P concentrations, and (C_p, C_n:) K concentrations for plantation and natural tree needles, respectively. Different letters in the legends of the figures indicated a significant difference due to needle ages (p < 0.05).

Among the *Pinus* species, the next most closely related species for which foliar nutrient data were loblolly pine (*P. taeda*) and ponderosa pine (*P. ponderosa*). Another possible comparative species may be lodgepole pine (*P. contorta)*, because the three *Pinus* species distribute extensively. The established critical N, P, K values and N: P ratios for the three *Pinus* species as: when N<12.0 g·kg^{-1}, P<1.2 g·kg^{-1}, K<5.0 g·kg^{-1} for lodgepole pine, and when N<11.0 g·kg^{-1}, P<0.8 g·kg^{-1}, K<4.8 g·kg^{-1} for ponderosa pine (Garrison *et al*. 2000), they have been considered as N-limitation, P-limitation and, K-limitation, respectively; when N=11.58–12.68 g·kg^{-1}, P=0.90–1.15 g·kg^{-1}, or N: P=11.03–12.87 g·kg^{-1} for loblolly pine (Piatek and Allen 2000), N and P seemed not to be the limiting factors to loblolly pine. Valentine and Allen (1990) demonstrated that when the N:P ratio =10.42 for loblolly pine plantations, the growth was limited by both N and P (Tessier and Raynal 2003). Considering the similar properties of Mongolian pine with the pine tree species reported by the researchers, we compared the foliar N, P, K concentrations and N: P ratios of Mongolian pine in the research areas with those of *Pinus* species.

As can be seen in Table 3, for both natural and planted Mongolian pine tree needles, N and P concentrations seemed to be in the adequate ranges, i.e., N or P might not be the absolute limitation nutrients. Especially, for the plantation tree needles, N and P concentrations were higher than the critical values of other *Pinus* species, which indicated that the growth of Mongolian pine trees were unlimited by N or P absolutely. The N:P ratio (mean value: 13.1) of natural Mongolian pine needles was in the adequate

ranges, which indicated a well-balanced nutrition status of the natural forests, however, the N:P ratio (mean value: 10.3) of planted Mongolian pine needles was not in the adequate ranges, which indicated an unbalanced nutrition status of N and P in the plantations. Foliar K concentrations in both natural and planted Mongolian pine tree needles were much lower than the critical values of other *Pinus* species (4.80 g·kg^{-1}), i.e., 2.19 and 1.93 g·kg^{-1} for natural and planted Mongolian pine needles, respectively (Tables 2, 3). This result might suggest that K was the limitation nutrient of Mongolian pine on sandy land. The ratios of N:K of both natural and planted Mongolian pine needles were higher than 3.0 for all age-gradient (Fig. 2C, Fig. 3), which exceeded the well-balanced range (N: K=1.0-3.0) of *Pinus* species reported by Tausz *et al*. (2004). This result also demonstrated that K might be the limitation nutrient of Mongolian pine on sandy land.

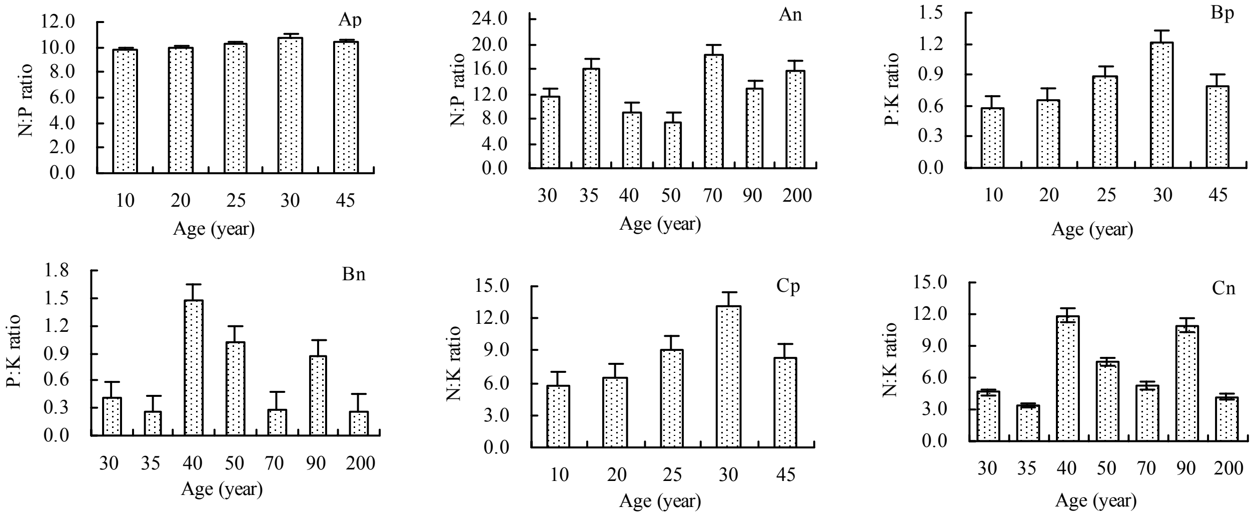

Fig. 2 Variation of N: P, P: K and N: K ratios with tree ages. (A_p, A_n) N: P, (B_p, B_n) P: K, and (C_p, C_n) N: K for plantation and natural trees, respectively.

Table 2. Total mean of foliar nutrient concentrations (g·kg^{-1})

Age	N		P		K		C		N:P		N:K		C:N	
(year)	NHHI	PKSL	NHHI	PKSL	NHHI	PKSL	NHHI	PKSL	NHHI	PKSL	NHHI	PKSL	NHHI	PKSL
10		15.94		1.62		2.77		499.87		9.8		5.75		31.36
20		15.38		1.54		2.36		492.69		10.0		6.51		32.03
25		14.00		1.36		1.54		494.65		10.3		9.08		35.33
30	12.58	14.57	1.10	1.35	2.68	1.11	479.13	495.73	11.5	10.8	4.69	13.09	38.08	34.02
35	12.17		0.76		3.69		486.81		16.0		3.30		40.00	
40	12.01		1.45		0.92		467.76		7.5		13.11		38.94	
45		15.64		1.50		1.89		492.51		10.5		8.28		31.50
50	12.87		1.94		1.72		479.02		6.6		7.49		37.21	
70	12.93		0.61		2.46		487.24		21.2		5.25		37.69	
90	11.94		0.94		1.10		486.52		12.7		10.90		40.74	
200	11.50		0.73		2.73		486.52		15.8		4.21		42.31	
*Total mean	12.29± 0.053^{a}	15.11± 0.080^{a}	1.07± 0.047	1.47± 0.012	2.19± 0.099	1.93± 0.065	481.86± 0.72^{b}	495.09± 0.30^{b}	13.1± 5.14^{c}	10.3± 0.38^{c}	6.99± 3.71	8.54± 2.87	39.28± 1.83^{d}	32.85± 1.75^{d}

*Values refer to means ± standard error, data with a, b, c or d indicate a significant difference between the values of natural and plantation tree needles (^{a}: t=4.3624, p=0.0018; ^{b}: t=6.8804, p=0.0005; ^{c}: t=2.1896, p=0.0356; ^{d}: t=6.1524, p=0.0001).

NHHI: Hulunbeier sandy land, Honghuaerji of Inner Mongolian Autonomous Region; PKSL: Keerqin sandy land, Zhanggu County of Liaoning Province.

Variation in foliar nutrient concentrations might be induced from the variation of soil nutrient availability, age differences of trees, or the inherent physiological differences among species (Koerselman and Meuleman 1996; Garrison *et al*. 2000; Alifragis *et al*. 2001). Here, we hypothesized that the foliar nutrient concentrations of natural Mongolian pine needles were in the adequate ranges, or in the well-balanced nutrition status, because the natural Mongolian pine forest has developed healthily. Compared with natural Mongolian pine needles, the N and P levels in the plantation tree needles were higher, especially, the foliar N concentrations of plantation tree needles was significantly (p=0.0018) higher than those of natural tree needles (Table 2). This result might be explained by that N availability in plantation tree needles could be easily accumulated by N fixation or N deposition in the research area (Chen *et al*. 2004), and this also implied that the N fixation or atmosphere deposition might be important for the N availability of the trees in the plantation area, because the litter (needles and branches) was removed by the local people. In addition, the foliar concentrations of N and P in planted Mongolian pine needles exhibited a decreasing trend

with the forest age (Fig. 1 A_p, A_n, B_p, B_n), but no such trend in natural Mongolian pine needles. This result meant that both N and P availabilities in soils essentially declined through the process of tree development without supplement of N and P as the litter losing. From the view of absolute nutrients of N and P, we could conclude that N or P might not be the absolutely limited nutrients for the Mongolian pine plantations, i.e., the plantation decline was not caused by the absolutely limited nutrients of N and P, at least in the current stage.

Table 3. Results of the literature research on foliar concentration of N, P, K or N: P ratios and nutrient limitation in coniferous forests

Study	Tree species	Location	N, P, K ($g \cdot kg^{-1}$) or N: P ratios	Limited By	Note
Karlssona and O¨rlander (2002)	**Scots pine** (*Pinus sylvestris*)	Sweden	N= 11.62–14.29		N, P and K all were below the optimum levels
			P= 1.31–1.48		
			K= 4.82–5.29		
Wang and Klinka (1997), summarized from literature	White spruce (*Picea glauca*)	British Columbia, Canada	N<10.5	N	Severe deficient
			10.5<N<13.0	N	Moderate deficient
			13.0<N<15.5	N	Slight deficient
			N>15.5		No deficient
			P<1.6	P	Slight or moderate deficient
			K<5.0	K	Slight or moderate deficient
			N:P>12.5	P	
Garrison *et al*. (2000), summarized from literature	Douglas-fir (*Pseudotsuga menziesii*)	Northeastern Oregon, USA	N<14.0	N	N, P, and K are critical foliar nutrient concentrations
			P<1.2	P	
			K<6.0	K	
	True/Grand-fir (*Abies grandis*)	Northeastern Oregon, USA	N<11.5	N	
			P<1.5	P	
			K<5.8	K	
	Lodgepole pine (*Pinus contorta*)	Northeastern Oregon, USA	N<12.0	N	
			P<1.2	P	
			K<5.0	K	
	Ponderosa pine (*Pinus ponderosa*)	Northeastern Oregon, USA	N<11.0	N	
			P<0.8	P	
			K<4.8	K	
Piatek and Allen (2000)	**Loblolly pine (*Pinus taeda*)**	North Carolina, USA	N=11.58–12.68	N	N and P did not seem to be limiting to growth when N:P=11.03–12.87
			P=0.90–1.15	P	
			N:P=11.03–12.87		
Rothe *et al*. (2003)	Douglas-fir (*Pseudotsuga menziesii*)	Oregon, USA	N=10.3–13.4		No indications of severe nutrient deficiency
			P=1.1–2.8		
			K=4.2–6.0		
	Norway spruce (*Picea abies*)	Bavaria, Germany	N=12.3 ± 1.4		Good nutrition status, well-balanced
			P=1.5 ± 0.85		
			K=5.0 ± 1.11		
Tausz *et al*. (2004), summarized from literature	Spanish Mediterranean pine (*Pinus pinaster*)	Germany	N=9.0–15.0		Adequate ranges
			P=0.9–1.5		
			K=3.0–5.0		
	Spanish Mediterranean pine (*Pinus halepensis*)	Germany	N=10.0–20.0		Adequate ranges, well- balanced N:P ratios ranged 7.0 to 10.0
			P=1.0–2.0		
			K >8.0		
	Radiant pine (*Pinus radiata*)	Germany	N=12.0–15.0		Adequate ranges, well- balanced N:P ratios ranged 7.0 to 10.0
			P=1.2–>1.4		
			K=3.0–7.0		
Tausz *et al*. (2004)	Canarian pine (*Pinus canariensis*)	Tenerife, Austria	N=7.1–10.7	N	
			P=0.8–1.5	P	
			K=5.3–10.4		
Tessier and Raynal. (2003), summarized from literature	Coniferous forest	Europe	N:P=7·0–14·5	Not N	
	Norway spruce (*Picea abies*)	Sweden	N:P=7.54	N	
	Norway spruce (*Picea abies*)	Sweden	N:P=9.8	N and P	Plantation
	Norway spruce (*Picea abies*)	Sweden	N:P>12·5	N	Plantation
	Douglas-fir (*Pseudotsuga menziesii*)	The Netherlands	N:P=8.00	N	
	Douglas-fir (*Pseudotsuga menziesii*)	The Netherlands	N:P=22–25	P	
	Scots pine (*Pinus sylvestris*)	Sweden	N:P=8·96	N	
	Loblolly pine (*Pinus taeda*)	North Carolina, USA	N:P=10·42	N and P	Plantation

Note: the species with bold font are similar to Mongolica pine in their ecophysiological characters

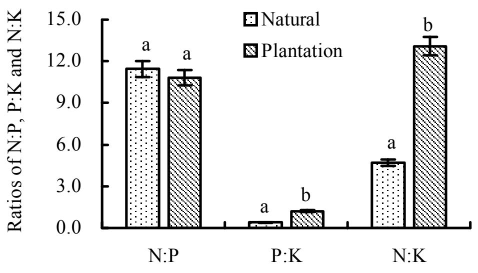

Fig. 3. Comparison of N: P, P: K and N: K ratios between plantation and natural trees with the similar tree age (mean values of 30 and 45 years old for plantation forest needles, 30, 35, 40 and 50 years old for natural forest needles). Different letters in the pair columns indicate significant difference between natural and plantation tree needles (p<0.05).

With respect to foliar K concentrations, the data set of both natural and planted Mongolian pine needles should be classified as the lower class according to the critical values reported in other *Pinus* species (>4.80 g·kg^{-1}) (Table 3); while, the foliar K concentration in the planted Mongolian pine needles (mean value=1.93 g·kg^{-1}) was lower than that in the natural Mongolian pine needles (2.19 g·kg^{-1}). If K was the limitation nutrient of Mongolian pine on sandy land, then it should be more severely in the plantation site.

As to the foliar nutrient ratios of N:P, there were significant differences between natural and planted Mongolian pine needles (p<0.05), the mean ratios of N:P in natural tree needles were 26.9% higher than those in plantation tree needles. The result indicated that there was a better balanced nutrition status in the natural forests than in the plantations.

Although there were no significant differences of foliar nutrient ratios of N:K between natural and planted Mongolian pine needles (p=0.05), the mean ratios of N:K in natural tree needles were 18.2% lower than those in plantation tree needles. This result also suggested that there was a better balanced nutrition status in the natural forest than in the plantation forest.

The other significantly different factors between natural and planted Mongolian pine needles were foliar C concentration and the ratio of C:N (Table 2). Generally, the initial chemical composition such as foliar N concentration, or index of C:N ratio has been widely employed as the decomposition predictors (Zhang and Zak 1995; Xuluc-Tolosaa *et al*. 2003). In particular, the initial C:N ratio as a general index can provide a broad indication of the decomposition potential because of correlated with higher microbial activity (Zhang and Zak 1995), i.e. the lower the C:N ratio (with high N concentration), the higher the decay rate, vice versa (Liao *et al*. 2000). Although foliar C concentration in planted Mongolian pine needles was significantly higher than that in natural Mongolian pine needles (495.09± 0.30 and 481.86± 0.72, respectively), the C:N ratio of planted Mongolian pine needles was significantly lower than that of natural Mongolian pine needles (32.85± 1.75 and 39.28± 1.83, respectively) (Table 2). These results indicated that the decomposition of natural Mongolian pine needles should be slower than those of plantation needles, i.e. the nutritional status of natural forest should be different with the plantation because of the different release rates of needles in natural and plantation forests.

On the other hand, most plants that grow in low nutrient environments produce long-lived leaves because there are insufficient nutrients to support rapid leaf turnover (Chapin 1980). Leaves that survive a long time have more structural cells to withstand unfavorable conditions and other secondary metabolites. For Mongolian pine, there always existed four–year-old needles, which reflected the long leaf span. But the trees in plantations were much higher than those in natural forests with the same ages. It was suggested that the trees in plantations always grew quickly than those in natural forests, which could be induced by the high nutrient cycling and nutrient use efficiency. So there might be a good nutrient balance between the growth of trees and environmental factors in natural forests.

From these results, if only considering the foliar nutrient concentrations (Fig.1, Table 2) of different provenances of Mongolian pine tree needles, we could conclude that the degradation phenomenon of Mongolian pine plantation was not induced by nutrition deficiency of absolute nutrients of N and P, but might be induced by K or other mineral nutrients. We could not judge if other mineral nutrients contribute to the degradation phenomenon of Mongolian pine plantations as we did not compare the other mineral nutrients in this study. The unbalanced nutrition status in the plantations may also contribute to the degradation phenomenon of Mongolian pine plantations. Additionally, the degradation phenomenon of Mongolian pine plantations might also arise from other causes, such as soil water deficiency, high tree density, plant diseases and insect pests, or tremendous variation of ecological conditions and long-term drought stress.

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